Resource Markets

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User Manual
Functional and Technical Documentation for the World Gas Model 2008

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User Manual

Functional and Technical Documentation for the World Gas Model 2008

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1 Introduction and outline of document

The World Gas Model (WGM) is a multi-period market equilibrium model for the global natural gas market cast as a Mixed Complementarity Problem (MCP). The WGM has been implemented in GAMS. This document provides backgrounds and details on the development of the WGM. It serves as technical documentation for the model functionality and data sets as wells as a manual to users. This document does not provide the mathematical formulation of the WGM. An extensive description of the mathematical model as well as the literature sources used for collecting the input data is given in Egging, Holz and Gabriel (2009a). This reference also covers the optimization problems of the different players and the market equilibrium conditions among players.

Section 2 provides a functional overview of the model: what market players are modelled, and how they do interact. In section 3 the file structure and program flow of the GAMS files are explained. Section 4 explains how the WGM should be used to run cases[1]. Section 5 provides an overview of the data sources and explains the model calibration. Section 6 describes the existing cases. Section 7 explains how new cases can be set up. Section 8 describes in detail how the model data sets can be extended with new players and infrastructure. Section 9 elaborates on the output reports that facilitate the analysis of the model outcomes. Section 10 provides an overview of the used abbreviations in the model. Section 11 concludes with listing conference publications and presentations for which the WGM has provided the material.

[1] The words *cases* and *scenarios* are generally used interchangeably. In this manual we have used the word *case*.

2 The World Gas Model

This chapter introduces the reader to the World Gas Model (WGM). The structure of the global natural gas market is laid out, and its representation in the model is specified. The geographic scope of the WGM is indicated and the representation of the natural gas trade flows in the model is explained in detail. Figure 1 shows an overview of the – about 75 – countries and regions that are incorporated in the World Gas Model (Egging et al., 2009a). For larger regions in the figure the numbers in parentheses indicate the number of sub-regions in the model. For example the US consists of six model nodes. A full list of nodes and regions is provided in Section 10 . The model covers 98% of the total production and consumption in 2005 according to BP (2008).

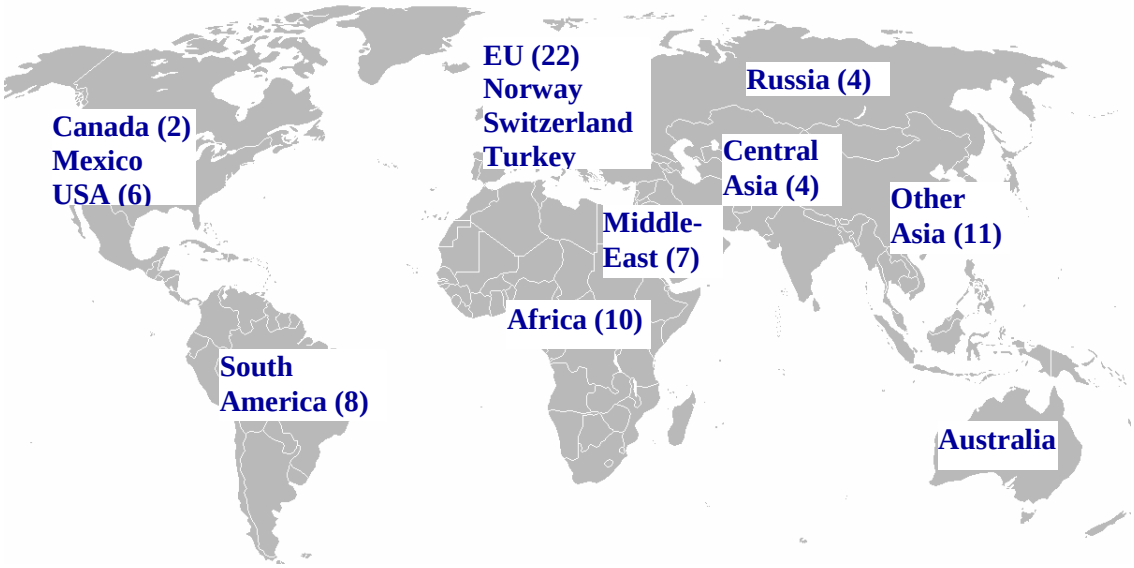

Figure 1 Geographic scope of the WGM[2]

Energy markets have many different types of agents and many possible interactions may occur among them. When formulating a model for an energy market many modelling decisions must be made regarding the representation of the actors. The following agents will be separately represented in the World Gas Model (WGM).

[2] Source for the blank map: http://en.wikipedia.org/wiki/Wikipedia:Blank_maps

Table 1 Market participants represented in WGM

Agent	Role
Producer	Produces natural gas and supplies it to its trading arm and – if applicable – domestic liquefiers
Trader	Buys gas from producers and sells it to marketers and storage operators (in countries accessible by pipeline)
Pipeline Operator	Assigns pipeline capacity to traders who need to transport gas from one country to another
Liquefier	Buys gas from the producer, liquefies it and sells it to regasifiers.
LNG shipping vessels	Facilitate the overseas-transport of LNG from Liquefiers to Regasifiers. (Represented in the model by distance-dependent costs and losses.)
Regasifier	Buys gas from liquefiers and sells it to the marketers and storage operators
Storage Operator	Buys gas in the low demand season from traders and – if applicable – regasifiers and sells it to the market in the high and peak demand season to take advantage of seasonal price differentials.
Transmission System Operator	Responsible for pipeline network expansions[3].
Marketer	Buys natural gas from traders, regasifiers and storage operators and distributes it to end-users. (Represented by the aggregate inverse demand curve of the consumer segments)
End users	The three consumption sectors: power generation, industry and residential/commercial (see Marketer)

The represented market agents include: producers, traders, liquefiers, LNG shipping, regasifiers, pipeline operators, transmission system operators, storage operators, marketers and three end-use sectors: residential/commercial, power generation and industry. The interactions between the market participants are summarized in Figure 2 below. The market interactions can be explained as follows:

Producers supply gas to their trading arms as well as to domestic liquefaction facilities. Traders may transport gas via pipeline systems to other countries, or sell it domestically to marketers or storage operators. Liquefiers ship gas to re-gasification

[3] Anticipating further unbundling legislation we made the modeling choice to have pipeline expansion investments not included in the pipeline operators problem. Also, initially we thought that the pipeline operator might have an incentive to hold back in capacity investments thereby facilitating higher congestion revenues in future periods. The latter would be the case if the agent would be able to exert market power, but a perfectly competitively price-taking market agent will just invest as much as predicted by: marginal costs = marginal revenues.

terminals in other countries. Like traders, regasifiers also sell gas to marketers and storage operators. Both regasifiers and traders may exercise market power relative to the marketers.

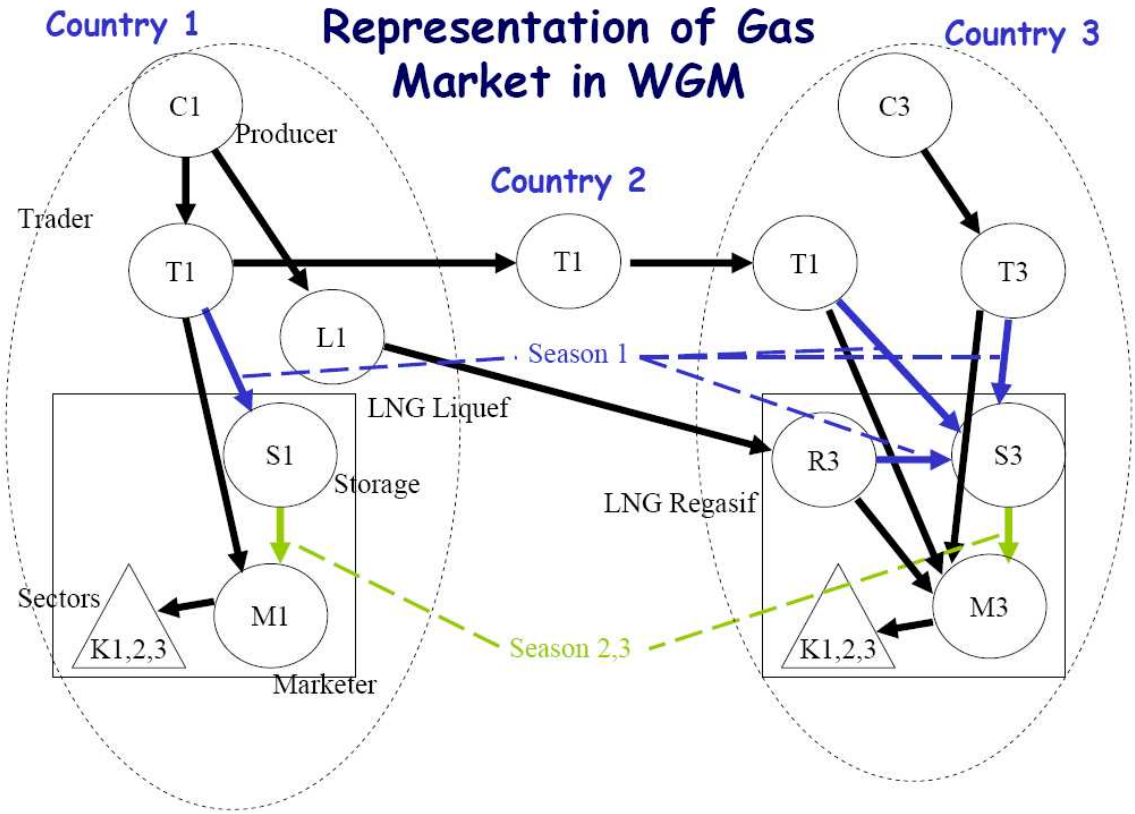

Figure 2 Natural gas supply chain as represented in WGM

The mathematical formulation of the optimization problems, market clearing conditions and the derived mixed complementarity problem can be found in Egging et al. (2009a).

3 Program Flow and File Structure

This chapter presents what happens in the WGM, in which order it does happen and where you can find the files you may need to change in order to implement and run cases. The folder structure and the program flow of the WGM are illustrated and explained. There are three hierarchy levels within the WGM structure: the source code and a number of auxiliary files; data and calibrations files; and case specifications. You may define as many cases as you wish and there are few restrictions on setting case specifications; you should, however, be careful about changing data and calibration files and the code structure.

3.1 Hierarchy and Program Flow

There are three hierarchy levels in the WGM structure (see Figure 3 and Figure 4 below). Firstly, there are the main source code `'WGM_DET_2.0.gms'` in the folder `'World_Gas_Model'` (`Main Folder`) and a number of auxiliary files in folder `'shared' (Aux Folder)`.

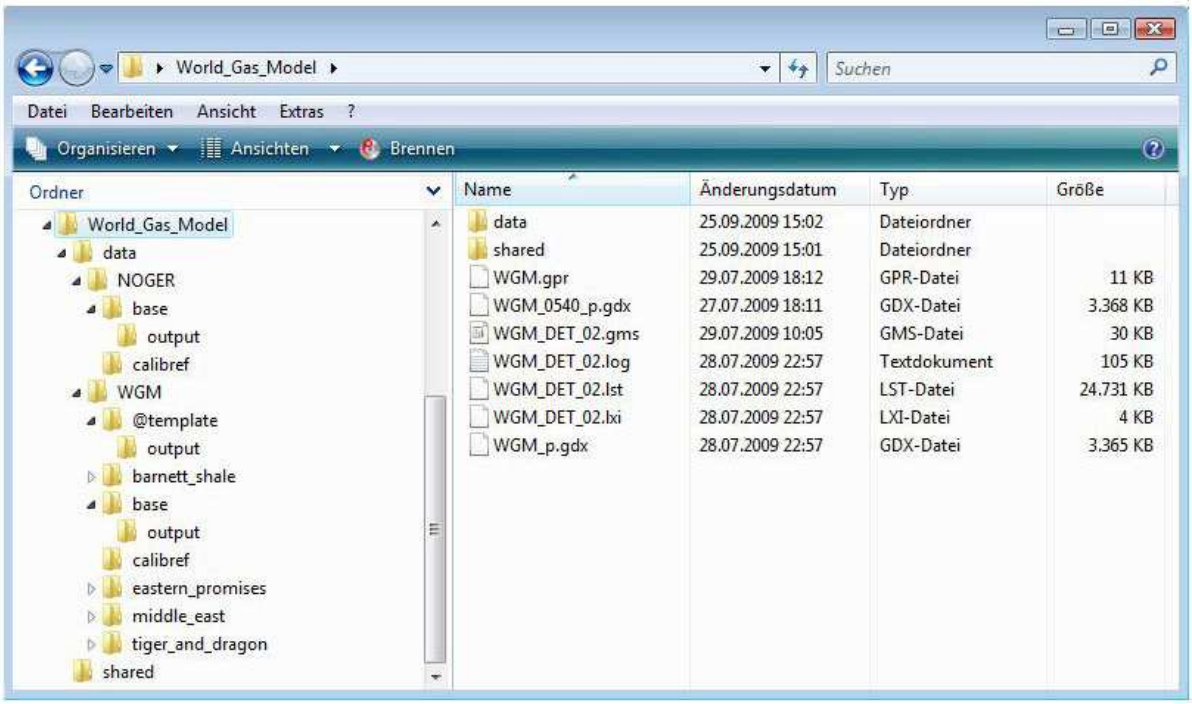

Figure 3 Folder structure of the WGM

The auxiliary files are files independent of the data set and case you are running, such as consistency checks, data processing and output report specification files. Other files that show in Figure 3 in folder World_Gas_Model (ending in .gdx, gpr, log, lst, lxi) are files produced by GAMS when running the model and can be ignored by the reader.

In folder `'data'`, you find one or more data sets of the following: `'WGM'` or `'RFF'` (the data sets for whole world); `'aggregate'` (the data set used in the INFRATRAIN) and `'NOGER'` (this test data set contains only fake data for two model nodes Norway and Germany and we use it in the manual to illustrate some analysis methods for the model results). In each of the data set folders, you find a folder named `'calibref'` (short for calibration-reference). This is the second hierarchy level of the WGM and it contains set declarations, reference values and data set mappings – it can be thought of as the basic input data for this data set. Figure 4 illustrates the folder structure of the WGM.

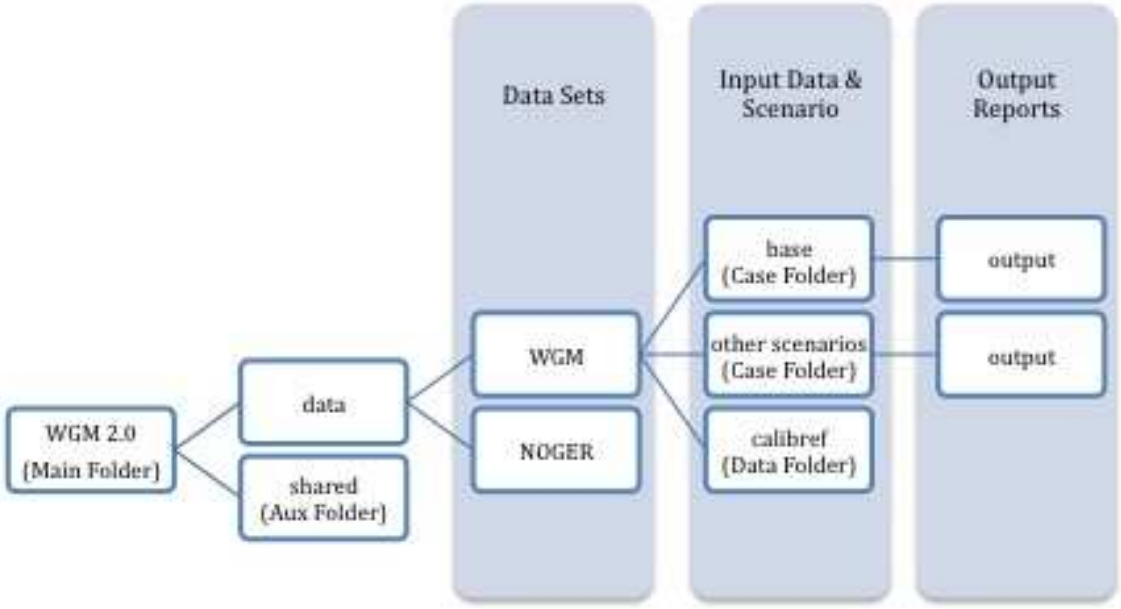

Figure 4 Hierarchy and folder structure of the WGM

The third hierarchy structure consists of the cases, which are also located in the data set folder. The `'base'` case does not make any changes to the initial input data. We

provide a number of other cases, which are described in more detail in Chapter 6 . Chapter 7 explains how to define new cases according to your own specifications.

A user that wants to run the model has to define three main parameters. The data set (`<dataset>`, e.g. WGM), the case (`<case>`, e.g. base) and the period (`<period>`, e.g. 0520 for the period 2005-2020). These parameters can be found at the top of the main source code `'WGM_DET_2.0.gms'`. The following describes the program flow when the running the model.

Figure 5 depicts the program flow of the WGM in relation to the hierarchy. The model first declares all parameters and sets (*Initialization*). It then reads the input data for the chosen data set. The input data are then modified according to the case specifications.

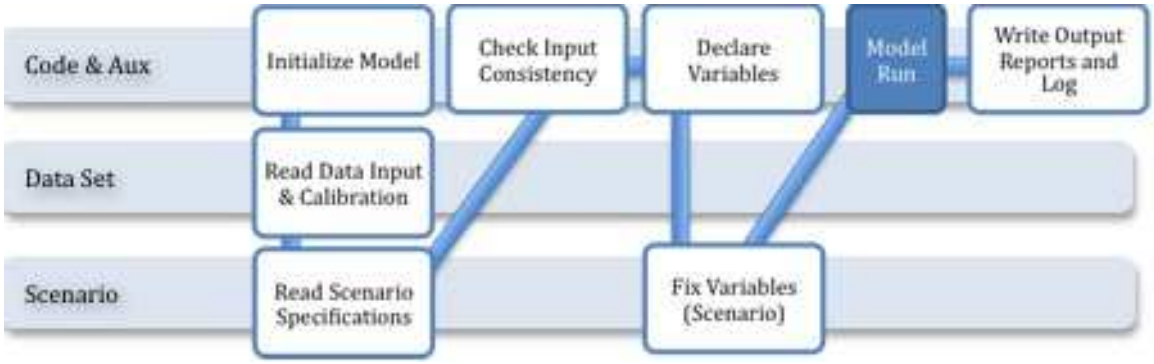

Figure 5 Program flow of the WGM

Next, the input data are adjusted according to the specifications in the calibref files and checked for consistency. If the model detects a problem (e.g., higher contract obligation than production capacity in a country), the model run is aborted and an explanation is written to a log file[4]. If no inconsistencies are detected, the WGM continues with declaring the model variables and equations.

In some cases, it might be convenient to set certain variables to predefined values (for instance, setting exports by a certain country to zero exogenously). This is done by

[4] `log_reading_input_<period>.txt` in the folder `/<case>/output/`

calling on a specific file in the case specifications: `in_var_fx.gms`. See section 4.1.3 for details.

Finally, GAMS casts the inputs into an equation system and calls the PATH[5] solver to attempt to find a solution. This can take several hours, depending on the computer and the size of the problem, and the time and iteration limits specified. If the run is successful (i.e. a solution is found, see chapter 4.3), GAMS creates a number of output reports in the `'/<case>/output/'`-folder. These reports and the log files are discussed in detail in Chapter 9 .

To summarize what GAMS does when you run the WGM:

1. Declare and define data sets and parameters
2. Adjust inputs according to case specifications
3. Calibrate input parameters
4. Consistency checks
5. Define variables and equations
6. Solve model
7. Produce output reports

3.2 Input Files

The data input, calibration and case specification files are separated by player type. In each of the input files, a header is inserted specifying the player type, all files specific for that type, the file location and which file you are currently looking at. For illustration, the header of the case file of the liquefier is shown in below:

```
$ONTEXT
inputs liquefiers
in_lng_data.gms          sets, mappings, data tables      Data folder
in_lng_calib.gms         calibration tuning parameters    Data folder
in_lng_case.gms          case specific adjustments        Case folder   THIS FILE
in_lng_assign_check.gms  assignments, input data checks   Aux folder
$OFFTEXT
```

[5] GAMS comes with a free MCP solver MILES, however we always use the proprietary PATH solver.

All files related to data input, data modification due to calibration and case specification are listed in Table 2. The colour code indicates how sensitive this file is to modifications, i.e. which files you may change without hesitation, and which files you should be careful modifying.

Table 2 File types associated with data input and case specifications

File name	Folder	Player type	Description
in_case_global.gms	Case	-	General parameters of case
in_<type>_data	Data	all	Data set
in_<type>_calib	Data	all	Calibration to match base year
in_<type>_case	Case	all	Case specifications
in_<type>_ ships_contracts	Data	Regas	LNG shipping contracts[6]
in_<type>_ market_access	Data	Trad	Market access
in_<type>_ market_power	Data	Trad, Regas	Market power specifications
in_var_fx.gms	Case	-	Fixing variables exogenously
in_<type>_assign_check	Main	all	Check inputs

Green – these are the case specifications. You can simply create a new case by duplicating the `'base'`-folder, rename the new folder (use a descriptive folder name without spaces) and change any parameters to describe the case you want to run.

Yellow – these are input data. If you change any of these, it might be necessary to recalibrate the model, which takes quite some time and skill. Before making any changes to these files, ask yourself why it does not suffice to make this change in one case only. Most users will not change these files, but will specify new cases only. However if you need to change these, Chapter 8 provided details on how and what.

Orange – these are check files to ensure that there is no contradiction in the input data, such as checks to ensure that there no producer has higher LNG contract obligations than production capacity or every producer has a trader to sell to. If the model encounters any problems, it will abort. Check the log-file to see where the problem

[6] Adding or changing contractual values upward may cause production or liquefaction capacities to be not sufficient anymore. The model will produce an error message if that is the case, however the user may want to verify her-/himself.

lies. Do not change anything in these files unless you are sure you understand the code. Make a backup anyway, just in case.

Instructions on how to create new cases are given in Chapter 7 .

3.3 Other file types

It is beyond the scope of this manual to describe all file types and their role in detail. An overview is given in Table 3. As mentioned above, when modifying these files, please be careful about what you do, keep a backup of the original file and test the new file (for instance, by comparing model results before and after the change on a small data set such as NOGER) before you interpret data from the modified model on a large data set.

Table 3 Other input file types

Include files	all_<?>.gms	These files list other files to be included in the model.
Output specifications	out_<?>.gms	These files define the data written in the output reports. The output reports generated at the end of a model run have the same name as the output report specification files.
Declaration	declare_<?>.gms	Declaring sets and parameters

3.4 Parameters & Variables, Sets & Mappings

Variable and parameter names in the GAMS code follow the mathematical formulation of the KKTs in Egging et al. (2009a) as closely as possible. Player sets are indicated by the first letter of the player type (P for the set of producers, L for the set of liquefiers, etc.). Elements of each set are prefixed by these first letters ('P_ALG' is the producer in Algeria, 'L_ALG' is the liquefier in Algeria).

An overview of variables in the WGM and their interpretation is listed in Table 4; an extensive list is given in the main source code 'WGM_DET_2.0.gms'.

To facilitate the reusability of data input files as well as the definition of cases for some sets, super and sub sets are defined where appropriate. For instance, PP is the super set of all producers that can exist in the model; P is a subset of producers

actually active in the model run.[7] Similarly, the set YYY consists of all years (2005 to 2040), the subset Y consists of only the years that are included in the model run, the time horizon over which the players optimize.

Table 4 Variables in the model and interpretation

Variable name	Applicable Player Types	Interpretation
Sales<type>_tot	A (arc), L, P	Total sales of player
Sales<type>to<type>	R, S, M; S, M	Sales (Decision variable Seller)
Buy<type>from<type>	L, R, S, T; P, L, R, T	Purchases (Decision variable Buyer)
Flow	T	Amount of gas shipped by pipeline (Decision variable Trader)
CapNew<type>	L, R, Pipe, Storage (Extr, Inj, WG)	Additional capacity
pi_W	Marketer	Wholesale (final demand) price
pi_<type>	L, P, RS (to Storage), TS (to Storage)	Selling price between players
phi_<type>	L, R, S, T	Dual to mass-balance constraint
alpha_<type>	A (arc), L, P, R, S	Dual to capacity constraint
beta_<type>	P, S (Extr)	Dual to horizon constraint
gamma_S	S	Dual to working gas constraint
eps_R	R	Dual to contractual purchases
rho_<type>	A (arc), L, R, Storage (Extr, Inj, WG)	Dual of capacity expansion constraint
tau_A	A (arc)	Congestion fee (dual to pipeline capacity constraint)

The model horizon is set in the first lines of the main source code; see the following chapter for more information. As a rule of thumb, input data is specified over the supersets, while the model equations are defined on the subsets.

An important part of the code are mappings; most of the equations are based on the country node set (n) or one of its subsets (n_prod is the set of production country nodes, n_cons is the set of consumption country nodes). Country nodes are prefixed

[7] E.g., a backstop supplier P_SUP is active only in the Post Bali Planet case in Huppmann et al. (2009).

by the letter N; the country node Algeria is named 'N_ALG'. Mappings tie together a player (e.g. a producer) and the country node where it operates. For example, P_ALG, the producer 'Algeria' and N_ALG. the country node Algeria are tied together by the following line of code (in file 'in_prod_data.gms'):

```
NdOfProd('P_ALG','N_ALG') = 1;
```

Similarly, ProdNdOfTrad(t,n_prod) maps trader *t* to production node *n*_prod and is used in the model when defining that a trader can purchase natural gas at the specific production nodes only. This mapping structure grants a lot of flexibility: for example, it allows tying more than one producer to a trader. All mappings are specified in the respective player type files.

To avoid erroneous inputs, there are a number of consistency checks implemented in the code, called before the solver is executed. For example, any producer cannot be tied to more than one country.

Naming conventions and mappings have been implemented accordingly for all other player types as well. When adding new players (for instance, a storage operator), make sure you add a mapping for this player; otherwise, the model does not know where it is located. (See section 8 for more details on how to add a player).

When you first see the WGM it may seem that the model set-up and file structure is overly complicated. Realise that the current set-up with all case specific changes completely separate from the data allows that several people can develop and run various sets of cases at the same time, and can easily integrate all the work by coping some folders from one PC to another.

4 Running the WGM

This chapter first presents some important GAMS specifics, which may go beyond the standard commands you learn when you first get to know the program. Knowing these will make your life much easier when you start to define your own cases. We then take you through the steps to actually run the model: where to modify commands, how to modify them, etc. Once the model terminates, you have to check whether GAMS found a valid solution, or whether the termination is due to a critical error or reaching a time or iteration limit.

4.1 Some GAMS specifics

In this manual, we assume that you are familiar with the basic structure and code syntax of GAMS. If not, please consult the GAMS tutorial by Richard E. Rosenthal[8] first. Once you have mastered the simple transport problem explained in this tutorial, there are some additional GAMS features which you may find useful. This is only a short introduction; for full documentation, we refer to the GAMS Users Guide[9].

4.1.1 The $ operator

The $ operator works much like the 'if'-command in any programming syntax. Look, for instance, at the following line:

```
Current_Parameter(element)$(Help_Parameter(element)>0) =
          New_Parameter(element) ;
```

If the value of `Help_Parameter` for *`element`* is positive, the value of `New_Parameter` is assigned to `Current_Parameter` with respect to `element`. Otherwise, the value is not changed. Keep in mind that GAMS considers a positive value to be `TRUE`, so the following would work identically:

```
Current_Parameter(element)$Help_Parameter(element) = New_Parameter(element);
```

[8] www.gams.com/dd/docs/gams/Tutorial.pdf

[9] http://www.gams.com/dd/docs/bigdocs/GAMSUsersGuide.pdf

A very useful application of the $ operator is as a selection mechanism, e.g. for summing the sales volumes of only the producers mapped to a specific node n:

```
…
sum(p$NdOfProd(p,n), SalesP_tot(p,d,y))
…
```

In this summation only the producers *p* are selected for which NdOfProd(p,n_prod)has a positive value (i.e. only the producer which is active at that node).

4.1.2 The ORD and CARD operators

These operators are used to count elements belonging to a set. ORD(element) returns the place at which the element occurs in the set it belongs to. CARD(set) returns the total number of elements in this set.

For example if we have a SET X/A,B,C/ then:

ORD('B') returns 2 (B being the second element in the set), and

CARD(X) returns 3 (because of the presence of three elements in the set).

4.1.3 Fixing Variables

You may want to set certain variables to specific numeric values. For instance, we use this approach in the 'Eastern Promises'-case (Huppmann et al., 2009) to set exports from Russia to zero after 2010. Due to the program flow in the WGM, it is only possible to fix variables in one certain file in the case specifications (in_var_fx.gms).

The following example from the 'Eastern Promises' case fixes the sales of the Russian trader to any country in Europe after 2010 to zero, i.e. Russia cannot sell to European consumers. This is achieved by the following line:

```
SalesTtoM.fx('T_RUS',n,d,yyy)$(ORD(yyy)>2 AND InSRegion(n,'EUR')) = 0;
```

This line of code means the following: sales to marketers [SalesTtoM] by the Russian trader [T_RUS] in any country [n] in the region Europe

[InSRegion(n,'EUR')] is fixed [.fx] to zero for all periods after the second [ORD(yyy)>2](since 2010 is the second element in the set of years 'yyy'.[10]).

WARNING: Fixing variables is not recommended for most users. One needs to be very careful to fix variables to specific values. The number of equations and the number of variables in an MCP must equal ('square system') and in many situations fixing values will result in a not square system.

4.1.4 Global Variables

It is possible to define global variables in GAMS using the following command:

```
$SETGLOBAL name "value"
```

During the compilation, each occurrence of %name% is replaced by value in the subsequent code. We use this mechanism, for example, to specify the data set, period and case to be used when executing the model.

4.2 Executing the WGM

In order to run the World Gas Model, you have to open the main source code file, namely WGM_DET_2_0.gms. At the very top, you find the following lines:

```
*****************************************************************
*                 MAIN SETTINGS
*****************************************************************
$SETGLOBAL dataset "WGM"
$SETGLOBAL case    "base"
$SETGLOBAL period  "0540"
```

These three are the settings, which you need to modify every time you run a case. Unless you want to introduce very specific changes in the model, you actually do not need to change anything else in the main source code but these three lines. The parameter dataset can be either 'WGM' for the dataset containing the whole world, or 'NOGER' (Norway and Germany) for the test data set. The parameter case specifies which case you want to run. The value assigned here must match the folder name of the case in the data set folder. (See Figure 3 at page 8.) The parameter

[10] Note that subset y is not considered to be an ordered set, therefore the super set needs to be used in the ORD() statement

`period` allows you to run the model over the total time horizon (2005-2040; '`0540`') or only for shorter periods (reducing the period in five year steps: '`0535`', '`0530`', etc.). Please keep in mind that one should maintain 2005 as the start year since the model has been calibrated on that basis.

4.3 Validating a model solution

A WGM run for the full time horizon may take several hours on a standard PC; depending on the changes implemented in the case, the run time may be substantially longer. When GAMS terminates, look for the `solve summary` in the `WGM_DET_2_0.lst`-file (double click on the word in the left window pane.). A valid solution looks like the following:

```
S O L V E     S U M M A R Y
     MODEL   WGM
     TYPE    MCP
     SOLVER  PATH                FROM LINE  5282
**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      1 OPTIMAL
```

The keywords here are solver status '`1 NORMAL COMPLETION`' and the model status: '`1 OPTIMAL`'. The model status is repeated at the end of the `lst`-file, and one sentence is written whether the run was successful.

```
----   5286 Model Status:
            MODEL WGM.ModelStat            =        1.000
----   5288 If this is displayed the model did solve correctly.
```

Output reports are generated only if the model status is at least locally optimal (Model Status: `2 Locally Optimal`). You should now proceed to check whether the results actually make sense given your model changes; how to do so is explained in the following chapters.

4.4 Error Messages

Most errors you are likely to encounter – apart from compilation errors due to typos – can be divided into two groups: invalid input data, and errors that are due to model infeasibility.

4.4.1 Errors due to invalid input data

WGM carries out several checks before starting the PATH solver, regarding set and mapping consistency (e.g. each producer is linked to exactly one trader and one country) and input data consistency (e.g., making sure that production capacity is sufficient to meet export LNG obligations). If an inconsistency is detected, the model run is aborted; check the log file `log_reading_input_<period>.txt` in the output folder.

4.4.2 Model infeasibility

Fixing variables or harsh parameter changes can lead to model infeasibility, i.e. PATH is unable to find a valid solution to the model; the solve summary shown above will then show a value for the `Model Status` higher than 2. In order to locate the problem, remove the asterisk before the `$OFFLISTING` command at the top of the main source code and rerun the model. When the solver terminates due to model infeasibility, search for occurrences of '`INFES`' and '`****`'in the `lst`-file. They might give you a hint where to look for the problem, i.e. which equations or variables cause the infeasibility.

4.5 Initialising a solution

It is possible to let the PATH solver start from an earlier model solution (for instance, the base case results). Initialising a model run has an unpredictable impact on the run time, unless the model and data are exactly the same in which case PATH merely needs to check the solution. E.g., when one wants to create an extra output column in a report this is a very handy feature. Every time you run the WGM, a GDX file (GAMS Data Exchange) named `WGM_p.gdx` is saved in the main folder[11]. If you want to use this file for a case run, you have to rename it to `WGM_<period>_p.gdx` and save it in the case folder of the case you want to use it with. In the main file, you find the following lines:

[11] This is done by setting option `Savepoint=1`;

```
*******************************************************************************
****                DEVELOPER'S AND TEST SETTINGS
*******************************************************************************
*Unmark if want to initialize the solution
$SETGLOBAL setinitsoln "*"
*Unmark debug if want more info in listing file
$SETGLOBAL debug "*"
```

Deleting the asterisk in `setinitsoln "*"` lets GAMS look for a GDX file in the case folder – if it doesn't find one, the model run will abort or just start from scratch!

In order to successfully initialise a case run, the number of variables in the gdx file and the case must match; i.e., adding a player or a pipeline means that you cannot initialise from a previous `gdx` file. In addition, the solution of the `gdx` file must lie in the feasible region of the case run; i.e., restricting a value to a level lower than the solution will return an error message (e.g. a lower value for production capacity than the actual production volume in the solution saved in the `gdx` file).

5 Data sources and calibration

This chapter provides an overview of the data on which the WGM is based: sources from which the data was collected, and how we proceeded to make data from different sources consistent.

Table 5 Data source overview

Data category	Data types	Sources[12]
Producer	Production cost parameters, capacities, development of production capacities and costs	Natural Gas Information, (IEA 2007); Oostvoorn et al (2003); OME 2005; Stern 2006. Statistical Review of World Energy (BP 2008), WEO 2006, 2008; EC Trends in European Transport and Energy (2005, 2007)
Trader	Market power	Model team choice, with some adjustments during calibration
Pipeline Operator	Distance and type of pipelines (onshore/offshore/ long-distance) pipeline fees	World Energy Outlook (IEA 2008); GTE (2005); Black Sea Energy Survey, (IEA 2000); Statistical Review of World Energy. (BP, 2007); EIA Website; South American Gas Daring to tap the Bounty, (IEA 2003).
Liquefier	Trade flows, capacity, costs, losses, conversion factor, LNG contracts, projects under construction/planned, investment costs	Natural Gas Information, (IEA 2007); Statistical Review of World Energy. (BP, 2007); The Global Liquefied Natural Gas Market, (EIA 2003); LNG Fact Sheets, (BG LNG Services 2005); LNG Map, (GLE 2005).
LNG shipping vessels	costs and loss rates, distances	Colton Company, www.distances.com
Regasifier	see Liquefier	see Liquefier
Storage Operator	Working gas capacity, extraction and injection rate, costs, losses	Natural Gas Information, (IEA 2007); Oostvoorn et al. (2003) OME 2005; Natural Gas in Western Europe, (Eurogas 1998); Flexibility in Natural Gas, (IEA 2002).
Transmission System Operator	Projects under construction/planned, investment costs	Personal communication (ICF Consulting, 2008); Developing China's Natural Gas Market, (IEA 2002); World Energy Outlook, (IEA 2005, 2008).
Marketer		see End User
End users	Consumption by sector, price-elasticity, development of consumption by country	Energy Statistics Manual, (IEA 2005); Statistical Review of World Energy. (BP, 2007); EIA Website; Annual Report 2005, (GasTerra 2006). WEO 2006, 2008; EC Trends in European Transport and Energy (2005, 2007)

[12] For periodic publications, only the most recent version used is stated; if these did not contain all the needed inputs earlier versions have been used as well.

5.1 Overview of data sources

The sources from which we collected the input data for the WGM are listed in Table 5. See Egging et al. (2009a) for further details.

5.2 Calibration

At some point when the model has been thoroughly checked and tested on a small data set we trust that the implemented functionality is as desired. The next step is to compile all the collected data in an appropriate format for GAMS to use. When one runs the model on the full data set, typically the outcomes are not as desired. Model outcomes for some countries' production are too high, for others too low. Outcomes for consumption and prices deviate from observed, acceptable or required outcomes. Et cetera. Some reasons for the deviations between model outcomes and desired outcomes are: inconsistencies in the data, unavailability or unreliability of the data sources or the necessary assumptions and simplifications and aggregations when specifying the model. An important step in model development is *calibration*, loosely speaking: the tuning of the input parameters to facilitate that model outcomes (for a reference case) are equal to (or close enough) to desired outcomes.

The person who calibrates the model has several decisions to make. What are the desired outcomes? Which outcomes are most important to get close? What flexibility do I allow myself in changing input parameters? What input parameters should I keep as collected, and what are the ones that allow larger adjustments?

Typically we prefer to adjust the most unreliable data and the parameters that are completely analyst-determined. Also, if the focus of the analysis is on some part of the world, e.g. Europe, then the model outcomes for other continents need not be as carefully and closely tuned as for Europe. E.g. for Europe we may want to have production and consumption in all countries within 1% of the reference values; but for countries at other continents we may say within 3%, as long as the whole continent on an aggregate level is within 2%.

The first step should be to define the reference values for the desired aggregation levels. It is highly preferable to find as few data sources as possible that cover as much as possible of the model outcomes. Sometimes the data sources used when

collecting the input data sets are also good sources for the reference data, but not always. E.g. if we use IEA data as input for sector consumption levels in 2005, it makes sense to use those same data as reference values.

For every data category the collected input data are specified in files with names '`in_<type>_data`'. The adjustments made during calibration to have the Base Case outcomes match the reference values are specified in files: `in_<type>_calib`.

Most data specifications and adjustments are straight-forward adjustments of costs and capacity values. For example for the liquefiers the file 'in_lng_data.gms' contains a table with capacities (cap), loss rates (loss) and costs (lin):

```
Table LiqData(l,*)
        cap     loss   lin
L_AFR   182.6   0.12    30
L_ASP   264.1   0.12    30
…..
```

In the file in_lng_calib.gms, the collected values for costs are overridden with the following statement:

```
LiqData(l,'lin') = LiqData(l,'lin') + 25 ;
```

Which means that all costs (in $/kcm) are increased by 25 units, from 30 to 55.

Most other data inputs and adjustments have a similar form as for the liquefier. Due to the complicated functional form of the production costs curve, we give some more background for the specification of the input parameters of the production costs.

5.3 Production costs specification and calibration

The basic input data for the producer are in file: `in_prod_data.gms`. This file contains a number of tables and some separate parameters.

Table `ProdData` contains production cost function parameters and capacities. Dependent on the data set, the production rate is either set equal to the collected value for the production capacity (WGM full data set) or to the reference outcomes for

production (aggregate data set)[13]. The production horizon represents the gas reserves, but since we have no reliable reserves data these values are set to a high value to not be limiting[14]. The other parameters are used for the 'Golombek' production cost function. (Golombek et al. 1995.) $C(q) = (\alpha - \gamma)q + \frac{1}{2}\beta q^2 - \gamma(Q-q)\ln\left(\frac{Q-q}{Q}\right)$ For which the marginal supply cost curve looks like: $C'(q) = \alpha + \beta q + \gamma \ln\left(\frac{Q-q}{Q}\right)$. In here, Q is the production capacity, $\alpha > 0$ is the minimum per unit cost, $\beta \geq 0$ the per unit linearly increasing cost term, and $\gamma \leq 0$ a term that induces high marginal costs when production is close to full capacity. In Table `ProdData` the first parameter is α, the second parameter is the maximum per unit supply costs at full capacity when not considering the logarithmic term (*mmQ*, see `CostProdMaxMargQuadr` in the calibration file). The third parameter is the maximum per unit cost at 99.9% of capacity (since ln(0) is not defined.) (*mmG*, see `CostProdMaxMargGolombek` in the calibration file).

The straight line at the bottom in Figure 6 below is the line α=10. The linearly increasing line shows the combined effect of α = 10 and mmQ = 40. The upper curve is the marginal supply cost curve mmG=120, thus including all three parameters[15].

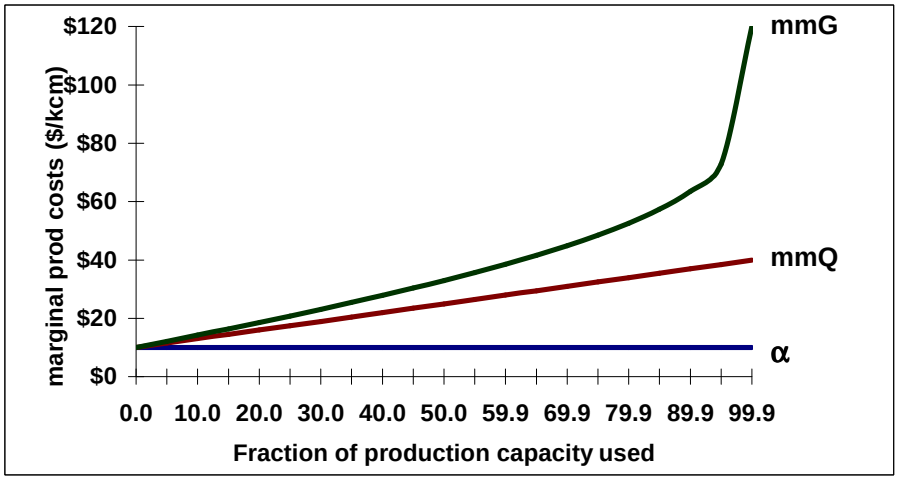

Figure 6 Marginal production cost curve for parameters α=10, mmQ = 40, mmQ = 120

[13] Allowing for slack in the production capacities in data set aggregate is done in the calibration.

[14] Except for the full data set, wherein for Netherlands we have implemented a production ceiling.

[15] Note that at production capacity usage over 99.9%, higher than γ costs per unit will apply (!)

Table `ProductionGrowthFactors` contains the growth rates of reference production levels in future years relative to the base year 2005.

Parameter `ProdCostGrowthFactor(pp,yyy)` is the multiplication factor indicating how the production costs for the producer rise over time.

5.3.1 Reference Data

The reference data for production are set at the bottom of `in_prod_data.gms`

5.3.2 Calibration Parameters

File `in_prod_calib.gms` contains the tuning parameters for the production data. The values for `CostProdMaxMargQuadr` ,`CostProdMaxMargGolombek` replace the second and third cost parameter of previous table `ProdData`.

Values for `ProdCostGrowthFactor` are overridden if necessary.

Tables `ProdData` and `ProductionGrowthFactors` provide the developments of the reference production levels over time. Typically one will need to adjust the production capacity, allow for some slack production capacity and also need to do some tuning. These purposes are all served by table `ProdCapCalibFactor`, which for every producer-year combination gives a multiplication factor to be applied to the reference value to get to the capacity value that will be input for the model.[16]

5.3.3 Model Inputs Parameters

The parameter values that are provided in the previously described files are not all literal input to the model. Some model input parameters are derived from the provided data. This is done in file `in_prod_assign_check.gms` in the `<shared directory>`. Several checks are performed to catch most of the inconsistencies.

6 Existing Cases

This chapter describes some of the cases which were published in previous articles using the WGM, see section 11.3 . They serve as examples to the reader on how to

[16] There have been many calibration adjustments to the production cost data relative to the collected data. Instead of applying all adjustments in the calibration file, in retrospect contrary to my better judgement, some of these data have also been adjusted in in_prod_data.gms

turn a research question into a WGM case, and how to quickly check whether results make sense.

The following cases were done based on the WGM and published in a number of articles. Due to slight changes to the model and the updated and differently aggregated data sets after the previous publications it is not guaranteed that rerunning these cases with the current model version would give the same numerical outcomes.

6.1 'Barnett Shale' – Higher production capacity in the US

The recent technological advances in unconventional natural gas production in the US have led to a reassessment of the development of the natural gas production capacities in North America, with great impact on the expected import dependency in the coming decades. Since no reliable data on actual size of reserves and production cost exist yet, we make rather crude assumptions.

6.1.1 Model changes

Production capacities from 2010 on are multiplied by 4 for the shale gas regions (US East, Gulf and Rockies) and by 2 for other US regions and Canada. Note that production cost depend on total production capacity; therefore, extending production capacity will lead, ceteris paribus, to lower unit production costs.

6.1.2 Highlight of case results

Production in North America roughly doubles, while consumption increases by approximately 20%. LNG imports are virtually non-existent, compared to an import dependency of 40% in the Base Case in 2030.

6.1.3 Note

The production capacity increase implemented here is very steep and large; a gradual rise might be more realistic. However, as the aim of this manual is to show how to implement a case, rather than developing ideal cases ourselves, we leave it to you to ponder on better assumptions regarding the actual production development in North America.

6.2 Investment freeze in the Middle East

We assume a complete halt on any new production capacity in the Middle East. This could happen as a result of political instability in the region, which deters investment in new installations for the next decades, or as a result of the formation of a gas cartel similar to OPEC, sharply constraining production in order to drive up prices. We aim to investigate the impact on consumer prices and the changes of LNG flows if the Middle East cannot expand its role as important natural gas supplier in the coming years, contrary to common projections.

6.2.1 Model changes

The production growth factors are set to zero from 2010 on for all Middle East producers. All contracted quantities from 2015 for Middle East exporters are reduced by half in order to allow more flexibility for Middle East producers to allocate their gas to consumers; otherwise, some producers would have to ship all their natural gas to only a limited number of countries or could not meet their obligations at all. Three new pipeline are allowed to be built, two from Oman and Qatar to Saudi Arabia, and one from Saudi Arabia to Kuwait, to see how trade in the region might develop.

6.2.2 Highlight of case results

Production in the Middle East still increases slightly over the whole period (rising prices allow movement along the supply cost curve; this is not a shift of the curve as would happen due to higher production capacity) compared to 2010. The total production remains at about 50% compared to the Base Case for 2040 levels. Prices increase worldwide, with the strongest increases in the Middle East itself (a more than threefold jump in Kuwait is the most extreme value). Still, the price increases on the Arab peninsula are not sufficient to warrant much more investment in pipelines there, compared to the Base Case. In the main consumption regions, price increases range from 3% to 25%.

6.3 'Tiger & Dragon' – India and China going large

This case simulates the effects of a strong demand increase in Asia, specifically China and India, and the implications on world natural gas trade flows.

6.3.1 Model changes

The demand growth factors in China and India were multiplied by the factor 2.5 from 2015 on compared to the base case assumptions. The maximum regasification capacity expansion parameters from 2015 on were multiplied by the factor 3 for the two countries in order to give sufficient leeway to accommodate higher demand. All maximum allowed expansions for pipelines leading to China and India, including those through transit countries (e.g. Iran-Pakistan-India), were doubled compared to the base case assumptions.

6.3.2 Highlight of case results

Consumption roughly doubles in the two countries until 2030, as intended. There is a price spike in 2015 in China and India, until investments catch up in the following periods. The imports into the ASPAC region are 288 bcm/y in LNG and 448 bcm/y by pipe, compared to 170 bcm/y as LNG and 326 bcm/y by pipeline in the base case. The Middle East exports most of its natural gas to ASPAC, while in the base case, the biggest recipient are the USA; Middle East exports to Europe are comparable in both cases.

7 Creating new Cases

The main aim of this manual is to enable the reader to investigate cases according to her or his own research questions. This chapter explains how to create new cases: first define a valid question; then define the data and input modifications necessary to implement the case and assess which files to modify; finally, screen the results whether the results make sense given your case assumptions.

7.1 Steps and advice

You read thus far, most likely with the aim to create cases according to your own research question. Follow these steps to create a new case:

1. Define a valid research question.
2. Put together the data changes necessary to implement the case, including set changes (e.g., new LNG facilities, one common trader for several countries (Gas Exports Cartel)).
3. Assess which files you have to change and how to change them (go back to Chapter 3 for more information). Figure out which parameters you need to change, how they are named in the model and on which sets they are defined.
4. Duplicate the `'base'` folder (or a case folder with similar model modifications), and rename the folder. Use a descriptive folder name without spaces. Implement all changes in the data and case files (see the sections on new players and pipelines – and consider our warnings in the following paragraphs about changing input data!).
5. Run the model on a short time horizon, and check how the changes show in these results and whether the output makes sense.
6. Run the model on the full time horizon, have a cup of tea and interpret the results.

Some advice when evaluating new cases:

- Always ask yourself if the results are plausible; if the effects of your changes are too small, the model may override or circumvent your restrictions; if the effects are too big, you may have – unknowingly – restricted the model more than you intended.

- When evaluating case results, you should always ignore (and leave out of any evaluation) the results of the last two periods. Investments need some future years to pay off. Therefore, the investment decisions and, consequently, production and supply decisions may be distorted in the last two periods of any run.
- Avoid changing any parameters for the base year 2005, since this will mess up calibration. E.g., if you specify new players, let them only be active in 2010 or later. (See Section 8.2).
- It is usually much easier and more straightforward to look at the modifications in the example cases provided than to figure out how to implement a change from scratch. If you want to implement a case with similarities to another one that has been specified already, you can copy the files and adjust them according to your needs.
- You might want to automate the evaluation of output reports, for instance by importing results into Excel spreadsheet templates. Keep in mind that adding new elements such as pipelines or players (e.g. a new liquefaction plant) will affect the number of variables in the output reports and may mess up your automation routine!

7.2 Adding new players - Outline

Please see section 8 for detailed specifics for each player.

When adding new players (e.g. a new regasification plant in a country which does not have one in the standard setup), follow the following steps:[17]

1. Add the player to the respective set (`declare_sets.gms` in the data folder)
2. Add a mapping for the player if necessary (`in_<type>_data.gms` in the data folder)

[17] Adding an additional plant to a node where this player type already exists is, from the model perspective, merely a capacity expansion and not a new player; this change can be made in the `in_<type>_data.gms` or `in_<type>_case.gms` respectively, depending on whether the new capacity is relevant for all cases or just some cases.

3. Provide all data for this player for the total time horizon (same file as above)
4. 'Switch on' the player in the respective case file (`in_<type>_case.gms`) if you want it to be active only in some cases; this can be achieved by setting capacity zero for all years in the input data and then changing these values in the respective case file

7.3 Specifics on production capacity

See also Section 8.8 .

There are two ways in which production capacity is influenced in the model: one is a capacity growth parameter, the second is the total reserve constraint. The capacity growth parameters are specified in the table `ProductionGrowthFactors(pp,yyy)` in `in_prod_data.gms`, located in the data folder. These parameters are based on projections regarding the development of the natural gas production potential of a country. These values implicitly incorporate the reserve constraint, as we have assumed that countries beyond their peak production have declining capacity (growth values lower than one mean declining production capacity).

The parameters are denoted as cumulative growth rates relative to 2005 values. Note that due to the way how the production cost function is calculated, a higher total capacity means lower production cost for the same amount of natural gas, ceteris paribus.

In addition to the implicit reserve constraint through the production capacities, there is also an explicit parameter provided in the model: column '`hor`' in table `ProdData(pp,*,*)`, located also in `in_prod_data.gms`. When this constraint is binding, the producers consider inter-temporal optimization a la Hotelling, applying a yearly discount rate of 10% in the Base Case (this value can be altered in the file `in_case_global.gms` in the case folder).

We only use the reserve horizon for the Netherlands in the Base Case to take account of a political commitment not to over-exploit their natural gas reserves. For all other producers, this value is set very high so as to not be binding in the Base Case.

7.4 Guidelines for creating new pipelines

See also Section 8.8

Adding new pipelines is a tricky exercise: there are two tables in the file `in_trad_data.gms` in the data folder defining pipeline parameters: `PipeData(n_out,n_in,*)` sets initial capacity, losses, the regulated fee and an 'existence parameter' ('`exists`'); `PipeInvParms(*,*,*)` sets the maximum capacity expansion and whether the pipeline is new, long and/or offshore (each affecting investment costs).

When adding new pipelines, insert all information in the in `in_trad_data.gms` file, but set the existence parameter to zero in the data. In this way, it will, for the time being, not affect your model results in the base case or any other case you investigate. In the case where you want to allow this pipeline to be built, add the following line in the `in_trad_case.gms` file, replacing the `n_out` and `n_in` with the appropriate nodes:

```
PipeData(n_out,n_in,'exists') = 1;
```

And now for the tricky part: adding a pipeline does not yet necessarily make any difference to the model! A pipeline can only be used by a trader if it is present (i.e. has market access) at both the start and end node of the pipeline. Market access has to be defined manually in the `in_trad_market_access.gms` file in the Data folder using the parameter `TransmAtNd(tt,n)`; this has to be set to 1 for a trader to be active at a demand node.

8 Modifying and adding data and set elements

Many cases can be implemented just using a set of case files. However, in some situations the model data set needs to be adjusted or extended with extra players. This section gives directions how to do that. In addition, this section provides a step by step tutorial for expanding the WGM data set with new players or infrastructure.

In general, the steps for adding a player are the following:

- Add player to set in `declare_sets.gms`
- Add mapping and player data to `in_<type>_data.gms`
  (for trader and regasifier resp. 2 and 1 other files need to be edited).
- Add player data to `in_<type>_case.gms`. It is advised to not make changes that would change the outputs for the year 2005.

Warning: the name country_node can be confusing. Due to the aggregation levels in some of the data sets – e.g. the data set `aggregate` that we have used in the INFRATRAIN – for several regions there is only one country node in the region. In data set `aggregate` the two exceptions are Europe, with five *country* nodes, and Russia, with two *country* nodes. To make the aggregation level explicit we can use the term model node instead of country node.

Make a complete backup before you start. Then duplicate the folder `base`, and rename the copy appropriately. We refer to the copy as `<case>`. After making your changes, check that the base case still produces the same outcomes.

8.1 Model node

A model node (country node) needs a region, and also other characteristics such as production, consumption, pipelines etc.

Files	**Edits**
calibref\ declare_sets.gms	add `N_NEW` to the set `N` "all nodes"
calibref\ in_assign_global.gms	In bottom part where the regions are specified: `InSRegion('N_NEW',<region>) = 1 ;`
OTHER	Need to add production, consumption or infrastructure information
WARNING	Not adding more information will result in an error message and abort

8.2 Producer

A new producer needs to be defined in two sets, a mapping to a country node, input data definitions and a trader to sell gas to

Files	Edits
calibref\ declare_sets.gms	add P_NEW to the set P "all producers" and add N_NEW to the set N "all nodes", and add N_NEW to the set N_prod "nodes of producing countries"
calibref\ in_prod_data.gms	Add mapping NdOfProd("P_NEW","N_NEW") = 1 ; Add a row to table ProdData for P_NEW * rate hor lin mmQ mmG P_NEW 0.1 10000000 20 45 70 HINT: By including a low production rate the results for the base case will not be disturbed. look at the other rows to get an idea about valid values Add a row to Table ProductionGrowthFactors for P_NEW with the all values = 1.00
calibref\ in_prod_calib.gms	Add row to Table ProdCapCalibFactor(pp,yyy), with all values = 1.00
CHECK	run the base case (for a short period, e.g. 0520, otherwise you will be waiting long) and look in the listing file or one of the output files for proof that N_NEW exists
<case>\ in_prod_case.gms	Override the production rate ProdData('P_NEW','rate')= <value in mcm/d> ; Prevent an error message for inconsistent data: ProdRef('N_NEW')=ProdData('P_NEW','rate') ; Override production growth factors (but not for 2005) ProductionGrowthFactors('P_NEW',yyy) = <value relative to the base year>; i.e., 1 means no growth
	Advanced overrides: ProdCostGrowthFactor(pp,yyy) = <value for production cost growth> ;
OTHER	A new producer needs to get a trader assigned, and also domestic consumption or liquefaction or pipeline outlets
CHECK	run the <case> case (for a short period, e.g. 0520, otherwise you will be waiting long) and look in the listing file or one of the output files for proof that N_NEW exists
CHANGING EXISTING <case>\ in_prod_case.gms.	There can have been made changes in the calibration. It is recommended to refer to data itself to make changes: ProductionGrowthFactors('P_XYZ',yyy)$(ORD(yyy)>2) = 2*ProductionGrowthFactors('P_XYZ',yyy) ;

8.3 Trader

8.3.1 Changing input parameters

For traders the most important characteristics are from which producers they can buy gas, what nodes and pipelines they can access, and what market power the exercise at all nodes.

Files	Edits
calibref\ declare_sets.gms	add T_NEW to the set T
calibref\ in_trad_data.gms	Affiliate trader with producer <n_prod> ProdNdOfTrad("T_NEW",<n_prod>) = 1 ;
calibref\ in_trad_market_access.gms	Define market access at <node> TransmAtNd('T_NEW,<node>) = 1;
<case>\ in_trad_case.gms	Define market power at <n_cons> (only needed if > 0) CournotPower('T_NEW',<n_cons>) = <value between 0 and 1>;
CHECK	run the <case> case (for a short period, e.g. 0520, otherwise you will be waiting long) and look in the listing file or one of the output files for proof that N_NEW exists, then run the <base> case (same)
OTHER	May need to define new pipelines
CHANGING EXISTING <case>\ in_trad_case.gms.	Granting access TransmAtNd('T_XYZ','N_ABC')= 1; Removing access TransmAtNd('T_XYZ','N_ABC')= 0; Overriding market power value CournotPower('T_XYZ', 'N_ABC')= <value between 0 and 1>;

8.3.2 Representing a cartel

Files	Edits
calibref\ declare_sets.gms	add a new trader `T_GEC` to set `T`, the set of traders
calibref\ in_trad_data.gms	add statement: `InGec('T_GEC')=1;`

<case> \ in_trad_case.gms	`InGec('T_GEC') = 0;`
	`InGEC('T_RUS') = 1;`
	`InGEC('T_AFR') = 1;`
	`InGEC('T_MEA') = 1;`
	`InGEC('T_SAM') = 1;`
	`InGEC('T_CAS') = 1;`
	
	Assign prod nodes to T_GEC
	`ProdNdOfTrad("T_GEC",n)$sum(t$InGEC(t),ProdNdOfTrad(t,n)) = 1;`
	Remove prod nodes from separate GEC traders
	`ProdNdOfTrad(t,n) $InGEC(t) = 0 ;`
	Assign T_GEC access to consumption nodes
	`TransmAtNd("T_GEC",n)$sum(t$InGEC(t),TransmAtNd(t,n))=1;`
	Remove access to consumption nodes for separate GEC traders
	`TransmAtNd(t,n)$InGEC(t) = 0 ;`
	Assign market power
	`CournotPower("T_GEC",n) = 1;`
	`CournotPower("T_GEC",n)$ProdNdOfTrad("T_GEC",n) = 0;`

<case>\ in_regas_case.gms	`RegasData(r,'cournot') = 1;`
NOTES	Due to different LNG and pipeline streams the above is merely a rough approximation of a cartel. Also the base year is affected by these changes. In cartel countries both the cartel trader and the domestic trader are active.

8.4 Consumption

A consumption node needs a reference demand level, sector shares and relative seasonal loads, information about demand projections, and incoming pipelines and or a regasifier

Files	Edits
calibref\ declare_sets.gms	if the node `N_NEW` pre-exists: add `N_NEW` to `N_cons (N)` "nodes of consuming countries" otherwise start with adding a model node (see previous sub section)

calibref\
in_cons_data
	Add a row to Table `ConsData(n,*)`
	`*  ref  res  ind  pg  low  high  peak`
	`N_NEW 0.03  0.33  0.33  0.34  1.00  1.00  1.00`
	→ res+ind+pg should add to 1.000
	→ 183*low+120*high+62*peak should add to 365, some rounding difference is allowed
	For a completely new country node with positive demand without domestic production, it is advised to take as a reference consumption value 0.03, and have an incoming pipeline or regasification terminal with capacity 0.1
	Add a row to Table `DemGrowthFactors(*,*)` for `N_NEW`, with all values 1.00

calibref\ in_cons_calib	add row to Table `ConsCalib(n,yyy)` for `N_NEW`, with all values 1.00
CHECK	run base case and check for proof that the consumption node exists

data\<case>\
in_cons_case.gms
	Define projections for the demand
	`DemGrowthFactors(<n_cons>,y) =`
	`<value relative to demand level in base year> ;`
	Note: these values should probably be quite large to make the 0.03 bcm/y included in `in_cons_data` grow to something significant.

	Advanced: `PriceGrowthFactor(n,y) = POWER(1+<%yearly adjustment>, YearStep*(ORD(yyy)-1))* PriceGrowthFactor(n,y);`
OTHER	a new consumption node needs a supply source. This can be (a combination of) local production, incoming pipelines (and access by traders) or regasification facilities.
CHANGING EXISTING <case>\ in_cons_case.gms	There can have been made changes in the calibration. It is recommended to refer to data itself to make changes. E.g doubling the reference demand from the second year on: `DemGrowthFactors ('N_XYZ',yyy)$(ORD(yyy)>=2) = 2 * DemGrowthFactors ('N_XYZ',yyy) ;`

8.5 Liquefier

A liquefier needs to be defined, get a mapping to a model node, data for capacity, losses, costs and expansions as well as shipping distances from its model node to regasifiers.

Files	Edits
calibref\ declare_sets.gms	add `L_NEW` to set `L` "Liquefiers"

calibref\ in_lng_data.gms	`NdOfLiq("L_NEW","N_NEW") = 1;`
	Add a row to Table `LiqData(l,*)`
	`*  cap  loss  lin`
	`L_NEW  0  0.12  30`
	Add a row to Table `MaxNewLiqCaps(l,*)` for `L_NEW`, all values 0

calibref\ in_regas_ships _contracts.gms	add shipping distances for the newly added liquefier to Table `ShDistance(n,r)`
NOTE	a liquefier needs a domestic producer
CHECK	do a base case run

<case>\ in_LNG_case.gms	It is not advised to add liquefaction capacity in the first year (2005):
	`LiqData('L_NEW',' cap') = <value cap in mcm/d> ;`
	If desired one can add liquefaction capacity in the second year (2010) :
	`LiqAddCapsHelp('L_NEW','curr') = <value cap in mcm/d> ;`
	Allowing liquefaction capacity expansions:
	`MaxNewLiqCaps('L_NEW',yyy) = <value in bcm/y> ;`

	Advanced:
	overriding operational liquefaction costs
	`LiqCostGrowthFactor('L_NEW',yyy) = POWER(1+PriceInfl,YearStep*(ORD(yyy)-1)) ;`
	overriding liquefaction expansions costs
	`LiqInvCostFx = (FACTOR) * LiqInvCostFx ;`

CHANGING EXISTING <case>\ in_LNG_case.gms	There can have been made changes in the calibration. It is recommended to refer to data itself to make changes.
	Adding capacity in the year 2010:
	`LiqAddCapsHelp('L_LNG,'curr')= LiqAddCapsHelp('L_LNG,'curr')+(5/0.365) ;`
	Allowing 50% higher capacity expansions
	`MaxNewLiqCaps('L_NEW',yyy) = 1.5*MaxNewLiqCaps('L_NEW',yyy) ;`

8.6 Regasifier

A regasifier needs to be defined, get a mapping to a model node and data for capacity, losses, costs and expansions as well as shipping distances from model nodes with liquefaction, a value for the market power parameter and possibly contracts information.

Files	Edits
calibref\ declare_sets.gms	add R_NEW to set R "Regasifiers"
calibref\ in_regas_data.gms	Add mapping NdOfRegas("R_NEW","N_NEW") = 1 ; Add a row to Table RegasData(r,*) * cap loss lin cournot R_NEW 0 0.015 10 0.25 Add a row to Table MaxNewRegasCaps(r,yyy) with all values 0
calibref\ in_regas_ships _contracts.gms	add shipping distances for the newly added regasifier to Table ShDistance(n,r)
NOTE	a regasifier needs domestic consumption
CHECK	run base case and check for proof that the newly added regasifier exists
<case>\ in_regas_case.gms	RegasAddCapsHelp('R_NEW','curr') = <value in mcm/d> ; MaxNewRegasCaps('R_NEW',yyy) = <value in mcm/d> ; CournotRegas("R_NEW") = <value between 0 and 1> ;
	Advanced: Adjust the future operating costs RegasCostGrowthFactor(rr,yyy) = POWER(1+PriceInfl,YearStep*(ORD(yyy)-1)) ; Adjusting the investment costs RegasInvCostFx = (FACTOR) * RegasInvCostFx ;
HINTS	SEE: data\<our_data_set>\calibref\in_regas_data.gms SEE: data\< our_data_set >\in_regas_ships_contracts.gms
CHANGING EXISTING <case>\ in_LNG_case.gms	There can have been made changes in the calibration. It is recommended to refer to data itself to make changes. Adding capacity in the year 2010: LiqAddCapsHelp('L_LNG,'curr') = LiqAddCapsHelp('L_LNG,'curr') + (5/0.365) ; Allowing 50% higher capacity expansions: MaxNewLiqCaps('L_NEW',yyy) = 1.5 * MaxNewLiqCaps('L_NEW',yyy) ;

8.7 Storage

Storage needs to be defined and mapped to a country with consumption, and data for working gas capacity, operating costs and expansions information.

Files	Edits
calibref\ declare_sets.gms	Add S_NEW to set S "storage operators"
calibref\ in_stor_data.gms	NdOfStor("S_NEW","N_ASP") = 1 ; Add row to Table StorData(s,*) with all 0 values, except for costs and losses.
<case>\ in_stor_case.gms	StorData('S_NEW','work') = <value in mcm> ; Add injection, extraction and working gas capacities in a specific year MaxInjectAdd ('S_NEW',<year>) = <value in mcm/d> ; MaxExtractAdd('S_NEW',<year>) = <value in mcm/d> ; WorkGasAdd ('S_NEW',<year>) = <value in mcm> ; Allowable capacity expansions in any year: StorData('S_NEW','inj_exp') = <value in mcm/d> ; StorData('S_NEW','xtr_exp') = <value in mcm/d> ; StorData('S_NEW','work_exp') = <value in mcm> ; Note: storage will only be used if there is seasonality in the demand. See Table ConsData(n,*) in calibref\ in_cons_data.gms and previous section on consumption data.
	Advanced: Adjusting operational storage costs StorCostGrowthFactor(s,yyy) = POWER(1+PriceInfl,YearStep*(ORD(yyy)-1)) ; Adjusting the investment costs InvCostSInjFx = (FACTOR) * InvCostSInjFx ; InvCostSExtrFx = (FACTOR) * InvCostSExtrFx ; InvCostSWGFx = (FACTOR) * InvCostSWGFx ;
WARNING	Adding storage to a country without consumption will result in an error message

8.8 Pipeline

Files	Edits
calibref\ in_trad_data.gms	Add a row to Table `PipeData` with all meaningful values but capacity 0 Add a row to Table `PipeInvParms` with meaningful values for the first three columns (New, Long, Offshore) but all allowable expansions a value of 0

<case>\
in_trad_case.gms
	Add allowable expansions
	`PipeInvParms(<n_out>,<n_in>,<year>) =`
	`<value in mcm/d> ;`

WARNING	Can a trader access both outward and the inward node?
CHECK	run a `<case>` case and a base case, note that capacity expansions often need at least two more periods after the expansion year to become profitable.

8.9 Other

Files	Edits
<case>\ in_case_global.gms	`discountrate = 0.10 ;` `priceinfl = 0.0313 ;`

9 Output Reports

This chapter introduces you to the output reports and the log file generated by the WGM, indicating prices, quantities produced and consumed, profits and investments in new capacity. Note that the last two periods of any run should not be included in any evaluation; they are needed to warrant endogenous investment decisions, but results in these last two periods may be distorted.

Each run of the WGM produces seven output reports, which are saved in the `'<case>/output'` folder. The following table provides an overview of the reports; more details are given below. If there does not exist an output folder in the case directory, the output reports are written to the main folder and they are given generic names. The output reports provide the most important results from the model runs; check the `WGM_DET_2.0.lst` file for more specific information (e.g. shadow values on investments).

When evaluating the reports, the last two periods of any run should be ignored and not included in any analysis. This is due to the fact that endogenous investment decisions in WGM need at least one future period to 'pay off' (i.e. to be warranted in economic terms). Therefore, the model might not build new capacity in the last periods, not because it is not economically viable but because the model horizon is limited. This can (will) lead to distorted results in the last few model periods.

Table 6 Output report overview

Report	File Name
Input Log File	log_reading_input_<period>.txt
Calibration Output	<period>_CalibrationOutputs.txt
Country-Season-Year	<period>_CountrySeasonYear.txt
Expansions	<period>_Expansions.txt
Trader Sales	<period>_Trader_Sales.txt
LNG Export	<period>_LNG.txt
Welfare & Profits	<period>_WelfareProfits.txt

The first line of each output report contains information regarding date and time, the time horizon, data set and case of the model run:

```
07/16/09;17:31;0540 ;WGM ;base ;
```

The second line specifies the report type and, for some reports, comments on units in the report or other important information.

9.1 Input Log File

This file is created before GAMS starts to compute the solution of the problem. If the run is aborted, check here for error messages. WGM checks a number of possible data conflicts before starting the computation, such as producers, which cannot sell to any trader or LNG contract obligations higher than export capacity. When adding pipelines or traders to the model, check here whether your changes show up in this report – if not, there is probably a mistake in your case specifications.

9.2 Calibration Output Report

This report compares input reference data (‘`Ref`’) to model outputs (‘`Out`’) and the relative difference (‘`Rel`’) for production and consumption, both by region and by country. If the values differ significantly and it is not due to a case change (e.g. a supply disruption in this particular country, expansion of production capacity), you may have made a mistake in the specifications.

9.3 Country-Season-Year Report

This output report lists production and consumption quantities, prices, exports and imports for all countries, all years and all seasons; see Table 7 for a detailed explanation of abbreviations in the report. Keep in mind that when calculating yearly values from this report, you have to multiply the daily values with the respective number of days for the season (stated in this report, too). This report also contains one column helping to calculate consumption-weighted average prices.

Table 7 Explanation and units for Country-Season-Year-Report

Heading	Explanation	Unit/Elements
Region	Region	see Section 10
Cntry	Country node	see Section 10
Year	Year	2005-2040
seas	Season	peak, high, low
days	Number of days in current season	integer
price	Final demand price	$/kcm
prod	Quantity produced at this node	mcm/day
extr	Quantity extracted from storage	mcm/day
pipein	Quantity imported by pipeline (all traders)	mcm/day
regas	Quantity imported via LNG	mcm/day
cons	Consumption of final demand at this node	mcm/day
liquef	Quantity exported via LNG	mcm/day
inj	Quantity injected into storage	mcm/day
pipout	Quantity exported by pipeline (all traders)	mcm/day
pr contr	Measure for world average price[18]	($ · mcm)
tdom c	Quantity sold by domestic trader to final demand	mcm/day
tdom s	Quantity sold by domestic trader to storage	mcm/day

9.4 Expansions & Investment Report

This report lists the capacity expansions for liquefaction, regasification, storage and pipelines. All values are given in mcm/d.

For liquefaction, regasification and storage capacity, three different values are given for each year. `<year>_add` lists exogenous capacity expansions defined in the respective input files, in a table called `<player>AddCapsHelp(*,*)`. These capacity expansions account for investment projects already completed at the time of writing, but which were not existent in the 2005 base year data. The report lists

[18] This measure is derived from [Domestic consumption x Number of days in season x Final Demand Price]; summing over a number of countries and dividing by the total number of days and total consumption in these countries yields the volume-weighted average wholesale price

cumulative capacity values. `<year>_exp` lists the endogenous capacity expansions per year, i.e. those pipeline capacities which are expanded and built by the Transmission System Operator. `<year>_tot` gives the total available capacity in each year, i.e. the sum of initial capacity and both exogenous and endogenous expansions. `TotExpans` is the sum of endogenous capacity expansions over all years. For pipelines, the total available capacity in each year is specified under (`<year>_cap`).

9.5 Trader Sales Report

This report gives all sales by the traders, i.e. all sales by the trader to final demand and the storage operators, both in their domestic nodes and of all quantities exported by pipeline. Note that the amount exported by pipeline from a producing country (this value is given in the country-season-year report) does usually not match the total sales in foreign markets due to losses in pipeline transports.

9.6 LNG Report

This report is the equivalent to the trader sales report for the LNG trade. Note that the values reported here are the amounts bought by the regasifier from the liquefier and do not consider losses during shipment and regasification. The total quantity bought by a regasifier in this report should therefore exceed the amount sold by that regasifier to the marketer and storage operator at its demand node (given in the country-season-year report).

9.7 Welfare & Profits Report

This report provides all information regarding consumer surplus and player profits by country and year. All values are given in 1,000,000 US $ and are NOT discounted. Most information is listed by country, except for trader information which, to avoid double-counting, is relegated to its own table. Table 8 provides a detailed explanation of abbreviations in the report. Note that congestion fees are not deducted from traders' profits, as they are not paid by the trader; the value can shed light, however, how much of the traders' profits are due to bottlenecks in the pipeline network.

Table 8 Explanation for Welfare & Profits-Report, in mio $, for country table

Heading	Explanation
Region	Region
Cntry	Country node
Year	Year
prodcost	Production cost
prodprof	Producer profit
lng cost	Liquefaction cost
lng prof	Liquefier profit
reg cost	Regasification cost
reg prof	Regasifier profit
storcost	Storage cost
storprof	Storage operator profit
conssurp	Consumer surplus
totspend	Total consumer expenditure
lng inv	Liquefaction capacity investment
regasinv	Regasification capacity investment
pipe inv	Inbound pipeline capacity investment
stor inv	Storage working gas capacity investment

Table 9 Explanation for Welfare & Profits-Report, in mio $, for trader table

Heading	Explanation
Region	Region
Trader	Trader
Year	Year
tradprof	Trader profit
reg fees	Regulated fees for pipeline transport
congfees	Congestion fees for pipeline transport

10 Appendix: Countries, Regions and Abbreviation

Country	Node	Region
Austria	AT	Europe
Baltic Region	BAL	Europe
Belgium & Luxembourg	BEL	Europe
Bulgaria	BG	Europe
Czech Republic	CZ	Europe
Denmark	DK	Europe
Finland	FIN	Europe
France	FRA	Europe
Germany	GER	Europe
Greece	GR	Europe
Hungary	HUN	Europe
Ireland	IRE	Europe
Italy	IT	Europe
Netherlands	NL	Europe
Norway	NO	Europe
Poland	PL	Europe
Portugal	POR	Europe
Romania	ROM	Europe
Slovak Republic	SLK	Europe
Slovenia	SLV	Europe
Spain	SPA	Europe
Sweden	SWE	Europe
Switzerland	SWI	Europe
Turkey	TRK	Europe
United Kingdom	UK	Europe
Algeria	ALG	Africa
Angola	ANG	Africa
Egypt	EGP	Africa
Equatorial Guinea	EQG	Africa
Libya	LIB	Africa
Morocco	MOR	Africa
Mozambique	MOZ	Africa
Nigeria	NIG	Africa

Country	Node	Region
Canada-East	CAE	North America
Canada-West	CAW	North America
Mexico	MEX	North America
USA-Alaska	USL	North America
USA-East	USE	North America
USA-Gulf	USG	North America
USA-Mid West	USM	North America
USA-Rockies	USR	North America
USA-West	USW	North America
Russia-East	RUE	Russia
Russia-Sakhalin	RUL	Russia
Russia-Volga-Uralsk	RUV	Russia
Russia-West	RUW	Russia
South Africa	SAF	Africa
Tunisia	TUN	Africa
Armenia	ARM	Caspian
Azerbaijan	AZB	Caspian
Georgia	GEO	Caspian
Kazakhstan	KZK	Caspian
Turkmenistan	TKM	Caspian
Uzbekistan	UZB	Caspian
Belarus	BLS	UKRBLS
Ukraine	UKR	UKRBLS
Argentina	ARG	South America
Bolivia	BOL	South America
Brazil	BRA	South America
Chile	CHL	South America
Ecuador	ECU	South America
Peru	PER	South America
Trinidad & Tobago	TRI	South America
Venezuela	VEN	South America

Country	Node	Region
Australia	AUS	Asia Pacific
Burma	BRM	Asia Pacific
Brunei	BRU	Asia Pacific
China	CHN	Asia Pacific
India	IDA	Asia Pacific
Indonesia	IDO	Asia Pacific
Japan	JP	Asia Pacific
Malaysia	MAL	Asia Pacific
Pakistan	PAK	Asia Pacific
Singapore	SIN	Asia Pacific
South Korea	KOR	Asia Pacific
Taiwan	THA	Asia Pacific
Thailand	TWN	Asia Pacific

Country	Node	Region
Iran	IRN	Middle East
Kuwait	KUW	Middle East
Oman	OMN	Middle East
Qatar	QAT	Middle East
Saudi Arabia	SAR	Middle East
United Arab Emirates	UAE	Middle East
Yemen	YMN	Middle East

Region	Abbreviation
Africa	AFR
Asia Pacific	ASPAC
Caspian Sea Region	CASP
Europe	EUR
South America	LATIN
Middle East	MIDEAST
Russia	RUSSIA
Ukraine & Belarus	UKRBLS
North America	USCNMX
Region of super-producer[19]	SUPER
World	WORLD

[19] The super-producer acts as a backstop supplier in the Post Bali case

11 References

In several cases the mentioned web sources only have more recent information available than what is used in the WGM data set. We still think that this information is beneficial to the users of this document.

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11.2 Publications based on the WGM

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11.3 Conference publications and presentations

For more, and the most-recent publications and presentations, see:

www.civil.umd.edu/~sgabriel/Research/presentations.html

www.ruudegging.com/resume/resume.htm#Presentations

www.tu-dresden.de/wwbwleeg/mitarbeiterseiten/fh/diwcvlong_en_fholz.pdf

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